PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Assistant Commissioner for Patents
United States Patent and Trademark Office
Box PCT
Washington, D.C.20231
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing (day/month/year) 04 May 2000 (04.05.00)	
International application No. PCT/US99/21475	**Applicant's or agent's file reference** 5000.113-1
International filing date (day/month/year) 16 September 1999 (16.09.99)	**Priority date** (day/month/year) 16 September 1998 (16.09.98)
Applicant SLATER, David, B., Jr.	

1. The designated Office is hereby notified of its election made:

[X] in the demand filed with the International Preliminary Examining Authority on:

05 April 2000 (05.04.00)

[ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was

[ ] was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO
34, chemin des Colombettes
1211 Geneva 20, Switzerland

Facsimile No.: (41-22) 740.14.35

Authorized officer

Antonia Muller

Telephone No.: (41-22) 338.83.38

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	**ES**	Spain	**LS**	Lesotho	**SI**	Slovenia
AM	Armenia	**FI**	Finland	**LT**	Lithuania	**SK**	Slovakia
AT	Austria	**FR**	France	**LU**	Luxembourg	**SN**	Senegal
AU	Australia	**GA**	Gabon	**LV**	Latvia	**SZ**	Swaziland
AZ	Azerbaijan	**GB**	United Kingdom	**MC**	Monaco	**TD**	Chad
BA	Bosnia and Herzegovina	**GE**	Georgia	**MD**	Republic of Moldova	**TG**	Togo
BB	Barbados	**GH**	Ghana	**MG**	Madagascar	**TJ**	Tajikistan
BE	Belgium	**GN**	Guinea	**MK**	The former Yugoslav Republic of Macedonia	**TM**	Turkmenistan
BF	Burkina Faso	**GR**	Greece			**TR**	Turkey
BG	Bulgaria	**HU**	Hungary	**ML**	Mali	**TT**	Trinidad and Tobago
BJ	Benin	**IE**	Ireland	**MN**	Mongolia	**UA**	Ukraine
BR	Brazil	**IL**	Israel	**MR**	Mauritania	**UG**	Uganda
BY	Belarus	**IS**	Iceland	**MW**	Malawi	**US**	United States of America
CA	Canada	**IT**	Italy	**MX**	Mexico	**UZ**	Uzbekistan
CF	Central African Republic	**JP**	Japan	**NE**	Niger	**VN**	Viet Nam
CG	Congo	**KE**	Kenya	**NL**	Netherlands	**YU**	Yugoslavia
CH	Switzerland	**KG**	Kyrgyzstan	**NO**	Norway	**ZW**	Zimbabwe
CI	Côte d'Ivoire	**KP**	Democratic People's Republic of Korea	**NZ**	New Zealand		
CM	Cameroon			**PL**	Poland		
CN	China	**KR**	Republic of Korea	**PT**	Portugal		
CU	Cuba	**KZ**	Kazakstan	**RO**	Romania		
CZ	Czech Republic	**LC**	Saint Lucia	**RU**	Russian Federation		
DE	Germany	**LI**	Liechtenstein	**SD**	Sudan		
DK	Denmark	**LK**	Sri Lanka	**SE**	Sweden		
EE	Estonia	**LR**	Liberia	**SG**	Singapore		

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 99/21475

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01L21/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	SPIESS L ET AL: "Aluminium implantation of p-SiC for ohmic contacts" FIRST EUROPEAN CONFERENCE ON SILICON CARBIDE AND RELATED MATERIALS (ECSCRM 96), HERAKLION, GREECE, 6-9 OCT. 1996, vol. 6, no. 10, pages 1414-1419, XP002129219 Diamond and Related Materials, Aug. 1997, Elsevier, Switzerland ISSN: 0925-9635	1-4,6,7
Y	page 1415, left-hand column, paragraph 1 -right-hand column, paragraph 3; figures 2,3	8,11,13, 14
	--- -/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 January 2000	15/02/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Micke, K

1

Form PCT/ISA/210 (second sheet) (July 1992)

Box III TEXT OF THE ABSTRACT (Continuation of item 5 of the first sheet)

The invention comprises a method for forming a metal-semiconductor ohmic contact (18) for use in a semiconductor device (10) having a plurality of epitaxial layers (14a-c) wherein the ohmic contact (18) is preferably formed after deposition of the epitaxial layers (14a-c). The invention also comprises a semiconductor device comprising a plurality of epitaxial layers and an ohmic contact.

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	WO 98 37584 A (UNIV PENNSYLVANIA ;SHENAI KRISHNA (US)) 27 August 1998 (1998-08-27)	15,16, 18-20
Y	page 7, line 5 -page 10, line 14; figures 3,10	8,11,13, 14,21, 22,24-27

X	DEV ALOK ET AL: "LOW CONTACT RESISTIVITY OHMIC CONTACTS TO 6H-SILICON CARBIDE" PROCEEDINGS OF THE INTERNATIONAL ELECTRON DEVICES MEETING,US,NEW YORK, IEEE,1993, pages 691-694, XP000481708 ISBN: 0-7803-1451-4	15-19,21
A	page 692, left-hand column, paragraph 2 - paragraph 5	3-6,8, 11-13, 22-25,27

X	CHEN J S ET AL: "CONTACT RESISTIVITY OF RE,PT AND TA FILMS ON N-TYPE BETA-SIC: PRELIMINARY RESULTS" MATERIALS SCIENCE AND ENGINEERING B,CH,ELSEVIER SEQUOIA, LAUSANNE, vol. B29, no. 1/03, 1 January 1995 (1995-01-01), pages 185-189, XP000513498 ISSN: 0921-5107	1,3-7
A	page 186, left-hand column, paragraph 1 - paragraph 3 page 187, left-hand column, paragraph 3 -right-hand column, paragraph 2; figure 3	8,11-14

X	US 5 409 859 A (GLASS ROBERT C ET AL) 25 April 1995 (1995-04-25) cited in the application	1,3-7
A	the whole document	8,11-27

Y	PATENT ABSTRACTS OF JAPAN vol. 1997, no. 07, 31 July 1997 (1997-07-31) -& JP 09 082663 A (FUJI ELECTRIC CO LTD), 28 March 1997 (1997-03-28)	21,22, 24-27
A	abstract; figure 1	1,2, 6-10,13, 14

	-/--	

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 99/21475

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	PORTER L M ET AL: "A CRITICAL REVIEW OF OHMIC AND RECTIFYING CONTACTS FOR SILICON CARBIDE" MATERIALS SCIENCE AND ENGINEERING B,CH,ELSEVIER SEQUOIA, LAUSANNE, vol. B34, no. 2/03, 1 November 1995 (1995-11-01), pages 83-105, XP000627607 ISSN: 0921-5107 page 93, left-hand column, paragraph 4 -page 96, left-hand column, paragraph 1 page 97, right-hand column, paragraph 3 -page 100, right-hand column, paragraph 1; tables 5,6,8,9 -----	1-27

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 99/21475

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9837584 A	27-08-1998	NONE	
US 5409859 A	25-04-1995	US 5323022 A	21-06-1994
		AT 177878 T	15-04-1999
		AU 4854693 A	29-03-1994
		DE 69324024 D	22-04-1999
		DE 69324024 T	12-08-1999
		EP 0659298 A	28-06-1995
		JP 8504298 T	07-05-1996
		WO 9406153 A	17-03-1994
JP 09082663 A	28-03-1997	NONE	

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
5000.113-1		
International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/US99/21475	16/09/1999	16/09/1998
International Patent Classification (IPC) or national classification and IPC H01L21/04		
Applicant [CREE RESEARCH, INC. et al.] CREE, INC.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 9 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 6 sheets.

CORRECTED VERSION

3. This report contains indications relating to the following items:

   - I ☒ Basis of the report
   - II ☐ Priority
   - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   - VI ☐ Certain documents cited
   - VII ☒ Certain defects in the international application
   - VIII ☒ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
05/04/2000	20.12.2000
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Krause, J Telephone No. +49 89 2399 2829

Form PCT/IPEA/409 (cover sheet) (January 1994)

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/US99/21475

I. Basis of the report

1. This report has been drawn on the basis of *(substitute sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments (Rules 70.16 and 70.17).)*:
Description, pages:

2-13	as originally filed	
1,1a	with telefax of	20/09/2000

Claims, No.:

1-20	with telefax of	20/09/2000

Drawings, sheets:

1/1	as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

   These elements were available or furnished to this Authority in the following language: , which is:

   - ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
   - ☐ the language of publication of the international application (under Rule 48.3(b)).
   - ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

   - ☐ contained in the international application in written form.
   - ☐ filed together with the international application in computer readable form.
   - ☐ furnished subsequently to this Authority in written form.
   - ☐ furnished subsequently to this Authority in computer readable form.
   - ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
   - ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:
- ☐ the drawings, sheets:

5. ☒ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)
   see separate sheet

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1 - 20
	No:	Claims	
Inventive step (IS)	Yes:	Claims	15 - 20
	No:	Claims	1 - 14
Industrial applicability (IA)	Yes:	Claims	1 - 20
	No:	Claims	

2. Citations and explanations
   see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

VIII. Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:
see separate sheet

Concerning Section I:

1. In claim 5 it is specified that the first anneal takes place at a temperature above 1000°C to 1300°C, ie possibly at a temperature higher than 1300°C. There is no basis for this feature in the application documents as originally filed, contrary to the requirements of Article 34(2)(b) PCT. In the original application and in original claims 5 and 12 the temperature is specified to lie between 1000°C and 1300°C.

2. In the examination claim 5 is considered to specify a temperature between 1000°C and 1300°C, as in original claim 12.

Concerning Section V:

I. Claims 1 to 7:

1. The article by L. Spieß et al.: "Aluminium implantation of p-SiC for ohmic contacts", First European Conference on Silicon Carbide and Related Materials (ECSCRM 96), Heraklion, GR, 6-9 October 1996, which appeared in: Diamond and Related Materials, vol. 6, No. 10 (August 1997), pages 1414-1419, XP002129219, Elsevier, CH, ISSN: 0925-9635, (= D1) describes a method of forming an ohmic contact to silicon carbide for a semiconductor device (cf. abstract and page 1415, section "2. Experimental"), the method comprising the steps of implanting at room temperature a selected dopant material into a surface of a silicon carbide substrate thereby forming a layer on the silicon carbide substrate having an increased concentration of dopant material, annealing the implanted silicon carbide substrate a first time, depositing a layer of metal on the implanted surface of the silicon carbide substrate, and thereafter annealing the metal and the implanted silicon substrate a second time at a temperature high enough to form an ohmic contact between the implanted silicon carbide and the deposited metal.

2. The subject-matter of claim 1 differs therefrom in that at least one epitaxial layer of

a material having a lower dissociation temperature than SiC is grown on the silicon carbide substrate opposite the implanted surface and that the temperature of the second anneal lies below a temperature at which a significant degradation of the at least one epitaxial layer would occur.

3. The person skilled in the art of semiconductor device fabrication has the desire to grow epitaxial layers on a substrate. The aim of the investigations forming the basis of D1 and the article by J.S. Chen et al.: "Contact resistivity of Re, Pt and Ta films on n-type [SPEC0803]-SiC: preliminary results", which appeared in: Materials Science and Engineering B, vol. 29, Nos 1/3 (1 January 1995), Elsevier Sequoia, Lausanne, CH, pages 185-189, XP000513498, ISSN: 0921- 5107, (= D2; cf. page 186, section "2.1 Deposition and annealing") is to form an ohmic contact to the SiC substrate, so that it is implicitly clear that epitaxial layers should be formed thereon, even if such layers are not mentioned in the articles. The person skilled in the art would further know which temperatures are damaging the epitaxial layer and choose the anneal temperature or the sequence of steps in this method accordingly, in particular since the values of the temperature specified in dependent claims 5 and 7 are known from document D2.

4. As a consequence, the person skilled in the art would obtain a method with all the features of claim 1 by a routine combination of the teaching of D1 with the teaching of D2 and his general knowledge. Claim 1 is therefore not considered to meet the requirement of Article 33(3) PCT.

5. The arguments of the applicants put forward in their telefax of 20 September 2000 are not convincing. According to D1 (cf. page 1414, right column, last paragraph) there are three steps of implantation, anneal, and contact formation. Since the implantation is performed to prevent the generation of a depletion region and since the anneal is necessary to activate the implanted impurities, it is clear for a person skilled in the art that these two steps should be performed before the metal is deposited. The second anneal is then needed to form the ohmic contacts, and it appears that the name "post implantation annealing" is erroneous in D1. The person skilled in te art would also conclude that two annealing steps are meant from the widely different temperatures of the two anneal steps.

6. The arguments of the applicants concerning document D2 cannot be accepted either, because in the cited passage of D2 (page 186, left column, first paragraph) a uniform doping concentration is only achieved for the first 250 nm of the SiC substrate having a thickness of 5000 nm. At least it does not appear to be possible to conclude therefrom that D2 cannot deal with substrates having an increasing dopant concentration.

7. The additional features of claims 2 and 3 fall into the competence of the average practitioner so that also claims 2 and 3 are not considered to meet the requirement of Article 33(3) PCT.

   It is however mentioned here that a claim clearly specifying the sequence of steps "1. first anneal, 2. epitaxial growth, 3. second anneal" could be considered to involve an inventive step.

8. The additional features of claims 4 and 6 are known from document D1 as well. Therefore claims 4 and 6 are not considered to meet the requirement of Article 33(3) PCT either.

9. The additional feature of dependent claim 5 is known from document D2, so that claim 5 does not appear to meet the requirements of Article 33(3) PCT.

10. The temperature of the second anneal step lies between 500°C and 900°C according to document D2. Since the person skilled in the art would choose the temperature according to circumstances, he would determine the upper boundary not to damage the epitaxial layers on the substrate and thus obtain a method with all the features of claim 7 without employment of inventive skill. Therefore claim 7 is not considered to meet the requirement of Article 33(3) PCT.

II. Claims 8 to 20:

1. Document D1 describes also a semiconductor device comprising a semiconductor substrate having a first and a second surface and a first conductivity type and a zone of increased carrier concentration in said semiconductor substrate and extending

from said second surface of said semiconductor material toward said first surface, and a layer of metal deposited on said second surface of said semiconductor substrate that forms an ohmic contact at the interface of said metal and said zone of increased carrier concentration.

2. The subject-matter of claim 8 differs therefrom in that at least one epitaxial layer of a material having a lower dissociation temperature than the substrate material is provided on said first surface of the semiconductor substrate.

3. The document WO-A-98/37584 (= D3) describes a semiconductor device (cf. page 9, line 8, to page 10, line 6, and Figs 2 and 17) comprising a semiconductor substrate (144) having a first surface and a second surface and a first conductivity type, at least one epitaxial layer (142, 146) on said first surface of said semiconductor substrate, whereby GaN having a lower dissociation temperature than SiC is used, and a layer of metal (148) deposited on said second surface of said semiconductor substrate.

4. The person skilled in the art would at least try to improve the contact between the electrode and the substrate in the device according to document D3 by applying the method of document D1 to a SiC substrate with a reasonable prospect of success. Claim 8 is therefore not considered to meet the requirement of Article 33(3) PCT.

5. The additional feature of claim 9 is known from both documents D1 and D3, so that claim 9 does not appear to meet the requirement of Article 33(3) PCT.

6. The arguments of the applicants in their telefax of 20 September 2000 concerning the relevance of document D3 are not convincing either. A specific performance of the device needs a specific doping profile, however, this would be adapted to an improved ohmic contact by a skilled process engineer using routine optimisation methods. Therefore the additional features of claim 8 do not impart inventiveness.

7. The additional features of claims 10 and 14 are known from document D1, so that claims 10 and 14 are also not considered to meet the requirement of Article 33(3) PCT.

8. The dopant concentrations in the substrate are apparent from document D1 (cf. Fig.

3) and fall into the competence of the average practitioner. Thus claims 11 and 12 are not considered to meet the requirement of Article 33(3) PCT.

9. The material of the epitaxial layer is known from document D3, so that also claim 13 is not considered to meet the requirement of Article 33(3) PCT.

10. The additional features of claim 15 with respect to claims 8 and 9, from which claim 15 is actually dependent, are the progressive decrease of the dopant concentration in the substrate and the use of a nickel contact on the second surface of the substrate. These specific choices are not evident from the available prior art, and therefore claim 15 is considered to meet the requirements of Article 33(2) and (3) PCT.

11. Claims 16 to 20 depend on claim 15 and therefore comprise all the features of claim 15. Since claim 15 is considered to meet the requirements of Article 33(2) and (3) PCT, also claims 16 to 20 are considered to meet these requirements.

Concerning Section VII:

1. Independent claims 1, 8, and 15 are not in the two-part form in accordance with Rule 6.3(b) PCT, which in the present case would be appropriate, with those features known in combination from the prior art (document D1 or D3, respectively) being placed in the preamble (Rule 6.3(b)(i) PCT) and with the remaining features being included in the characterising part (Rule 6.3(b)(ii) PCT).

2. Claim 15 comprises all the features of claim 8 and is therefore not appropriately formulated as a claim dependent on the latter (Rule 6.4 PCT).

Concerning Section VIII:

1. Claims 11 and 12 are directed to a device, and in this context the expression "initial concentration" is not quite clear, because an initial value refers to a state during the manufacturing process which cannot be inferred from the finished device any more (Article 6 PCT).

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference	FOR FURTHER ACTION see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
5000.113-1		
International application No.	International filing date *(day/month/year)*	(Earliest) Priority Date *(day/month/year)*
PCT/US 99/ 21475	16/09/1999	16/09/1998
Applicant		
CREE RESEARCH, INC. et al.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 5 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

   a. With regard to the **language,** the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

   [ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

   [ ] contained in the international application in written form.

   [ ] filed together with the international application in computer readable form.

   [ ] furnished subsequently to this Authority in written form.

   [ ] furnished subsequently to this Authority in computer readble form.

   [ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

   [ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. [ ] **Certain claims were found unsearchable** (See Box I).

3. [ ] **Unity of invention is lacking** (see Box II).

4. With regard to the **title,**

   [X] the text is approved as submitted by the applicant.

   [ ] the text has been established by this Authority to read as follows:

5. With regard to the **abstract,**

   [ ] the text is approved as submitted by the applicant.

   [X] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No. 1

   [ ] as suggested by the applicant.

   [X] because the applicant failed to suggest a figure.

   [ ] because this figure better characterizes the invention.

   [ ] None of the figures.

PATENT COOPERATION TREATY

From the INTERNATIONAL SEARCHING AUTHORITY

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL SEARCH REPORT OR THE DECLARATION

(PCT Rule 44.1)

To:
SUMMA, Philip
Attn. SUMMA, Philip
13777 Ballantyne Corporate Place
Suite 315
Charlotte, NC 28277
UNITED STATES OF AMERICA

RECEIVED
FEB 28 2000
PHILIP SUMMA P.A.

Date of mailing *(day/month/year)* 15/02/2000	
Applicant's or agent's file reference 5000.113-1	FOR FURTHER ACTION See paragraphs 1 and 4 below
International application No. PCT/US 99/21475	International filing date *(day/month/year)* 16/09/1999
Applicant CREE RESEARCH, INC. et al.	

1. [X] The applicant is hereby notified that the International Search Report has been established and is transmitted herewith.

Filing of amendments and statement under Article 19:
The applicant is entitled, if he so wishes, to amend the claims of the International Application (see Rule 46):

When? The time limit for filing such amendments is normally 2 months from the date of transmittal of the International Search Report; however, for more details, see the notes on the accompanying sheet.

Where? Directly to the International Bureau of WIPO
34, chemin des Colombettes
1211 Geneva 20, Switzerland
Fascimile No.: (41-22) 740.14.35

For more detailed instructions, see the notes on the accompanying sheet.

2. [ ] The applicant is hereby notified that no International Search Report will be established and that the declaration under Article 17(2)(a) to that effect is transmitted herewith.

3. [ ] **With regard to the protest** against payment of (an) additional fee(s) under Rule 40.2, the applicant is notified that:

[ ] the protest together with the decision thereon has been transmitted to the International Bureau together with the applicant's request to forward the texts of both the protest and the decision thereon to the designated Offices.

[ ] no decision has been made yet on the protest; the applicant will be notified as soon as a decision is made.

4. **Further action(s):** The applicant is reminded of the following:

Shortly after **18 months** from the priority date, the international application will be published by the International Bureau. If the applicant wishes to avoid or postpone publication, a notice of withdrawal of the international application, or of the priority claim, must reach the International Bureau as provided in Rules 90*bis*.1 and 90*bis*.3, respectively, before the completion of the technical preparations for international publication.

Within **19 months** from the priority date, a demand for international preliminary examination must be filed if the applicant wishes to postpone the entry into the national phase until 30 months from the priority date (in some Offices even later).

Within **20 months** from the priority date, the applicant must perform the prescribed acts for entry into the national phase before all designated Offices which have not been elected in the demand or in a later election within 19 months from the priority date or could not be elected because they are not bound by Chapter II.

Name and mailing address of the International Searching Authority	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL-2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Marjory Sastropawiro

Form PCT/ISA/220 (July 1998)

Box III TEXT OF THE ABSTRACT (Continuation of item 5 of the first sheet)

The invention comprises a method for forming a metal-semiconductor ohmic contact (18) for use in a semiconductor device (10) having a plurality of epitaxial layers (14a-c) wherein the ohmic contact (18) is preferably formed after deposition of the epitaxial layers (14a-c). The invention also comprises a semiconductor device comprising a plurality of epitaxial layers and an ohmic contact.

LOW TEMPERATURE FORMATION OF BACKSIDE OHMIC CONTACTS FOR VERTICAL DEVICES

FIELD OF THE INVENTION

The present invention relates to ohmic contacts to semiconductor materials. In particular, the invention relates to methods of forming ohmic contacts to devices that include a plurality of semiconductor materials.

BACKGROUND OF THE INVENTION

In the microelectronics context, circuits are made from the sequential connection of semiconductor devices. Generally speaking, semiconductor devices are operated by, and are used to control, the flow of electric current within specific circuits to accomplish particular tasks. To connect semiconductor devices in a circuit, appropriate contacts must be made to the semiconductor devices. Because of their high conductivity and other chemical properties, the most useful and convenient materials for making contacts to such devices are metals.

Metal contacts between semiconductor devices and circuits should interfere either minimally or preferably not at all with the operation of the device or the circuit. Furthermore, the metal contact must be physically and chemically compatible with the semiconductor material to which it is made or attached. The types of contact that exhibit these desired characteristics are known as "ohmic contacts."

An ohmic contact is usually defined as a metal-semiconductor contact that has a negligible contact resistance relative to the bulk or spreading resistance of the semiconductor, Sze, *Physics of Semiconductor Devices*, Second Edition, 1981, page 304. As further stated therein, an appropriate ohmic contact will not significantly change the performance of the device to which it is attached, and it can supply any required current with a voltage drop that is appropriately small compared with the drop across the active region of the device.

Ohmic contacts and methods of producing ohmic contacts are known in the art. For example, U.S. Patents 5,409,859 and 5,323,022 to Glass et al. ("Glass patents"), the entire contents of which are incorporated herein by reference, discuss an ohmic contact structure formed of platinum and p-type silicon carbide and a method of making the ohmic structures. Although ohmic contacts and methods of making them are known, the known methods for producing ohmic contacts, and especially

THAT WHICH IS CLAIMED IS:

1. A method for forming a metal-semiconductor ohmic contact for a semiconductor device, the method comprising:

implanting a selected dopant material into a first surface of a semiconductor substrate having a first conductivity type and wherein the implanted dopant provides the same conductivity type as the semiconductor substrate;

annealing the implanted semiconductor substrate a first time at a temperature and for a time sufficient to activate the implanted dopant atoms and increase the effective carrier concentrations;

depositing a metal on the implanted surface of the semiconductor material; and thereafter

annealing the metal and the implanted semiconductor material a second time at a temperature below which significant degradation of any epitaxial layers placed on the substrate would occur, but high enough to form an ohmic contact between the implanted semiconductor material and the deposited metal.

2. A method according to claim 1 comprising implanting the selected dopant material at room temperature.

3. A method according to claim 1 wherein the semiconductor substrate comprises silicon carbide.

4. A method according to claim 3 wherein the selected dopant material is selected from the group consisting of nitrogen, aluminum, arsenic, phosphorous, boron and gallium.

5. A method according to claim 1 wherein the first annealing is carried out at a temperature between about 1000°C to about 1300°C.

6. A method according to claim 1 wherein the metal is selected from the group comprising nickel, palladium, platinum, aluminum and titanium.

7. A method according to claim 1 wherein the second annealing is carried out at a temperature below about 850°C.

8. A method for forming an ohmic contact to silicon carbide for a semiconductor device, the method comprising:

implanting at room temperature a selected dopant material into a surface of a silicon carbide substrate thereby forming a layer on the silicon carbide substrate having an increased concentration of dopant material;

annealing the implanted silicon carbide substrate a first time;

growing at least one epitaxial layer on the silicon carbide substrate opposite the implanted surface;

depositing a layer of metal on the implanted surface of the silicon carbide substrate; and thereafter

annealing the metal and the implanted silicon carbide substrate a second time at a temperature below which significant degradation of the epitaxial layer would occur, but high enough to form an ohmic contact between the implanted silicon carbide and the deposited metal.

9. A method according to claim 8 wherein the step of growing the epitaxial layer on the silicon carbide substrate precedes the first annealing of the implanted silicon carbide substrate.

10. A method according to claim 8 wherein the step of growing the epitaxial layer on the silicon carbide substrate follows the first annealing of the implanted silicon carbide substrate.

11. A method according to claim 8 wherein the selected dopant material is selected from the group consisting of nitrogen, aluminum, arsenic, phosphorous, boron and gallium.

12. A method according to claim 8 wherein the first annealing the implanted silicon carbide substrate occurs at a temperature between about 1000°C to about 1300°C.

13. A method according to claim 8 wherein the metal is selected from the group comprising nickel, palladium, platinum, aluminum and titanium.

14. A method according to claim 8 wherein the step of annealing the silicon carbide substrate and the deposited metal occurs at a temperature below about 850°C.

15. A semiconductor device comprising:

a semiconductor substrate having a first surface and a second surface and a first conductivity type;

at least one epitaxial layer on said first surface of said semiconductor substrate;

a zone of increased carrier concentration in said semiconductor substrate and extending from said second surface of said semiconductor material toward said first surface; and

a layer of metal deposited on said second surface of said semiconductor substrate that forms an ohmic contact at the interface of said metal and said zone of increased carrier concentration.

16. A semiconductor device according to claim 16 wherein the semiconductor substrate is silicon carbide.

17. A semiconductor device according to claim 15 wherein the implanted dopant material is selected from the group consisting of nitrogen, aluminum, arsenic, phosphorous, boron and gallium.

18. A semiconductor device according to claim 16 wherein the initial carrier concentration in the silicon carbide is between about $1x10^{15}$ to about $1x10^{19}$ cm^{-3}.

19. A semiconductor device according to claim 18 wherein the carrier concentration in the zone of increased carrier concentration is between about $1x10^{18}$ and about $1x10^{20}$ cm^{-3} and is greater than the initial carrier concentration in the silicon carbide.

20. A semiconductor device according to claim 15 wherein said epitaxial layers are selected from the group consisting of gallium nitride; aluminum gallium nitride; indium gallium nitride; and oxides of silicon, gallium, aluminum and indium.

21. A semiconductor device according to claim 16 wherein said metal is selected from the group comprising nickel, palladium, platinum, aluminum and titanium.

22. A semiconductor device comprising:

a silicon carbide substrate having a first surface and a second surface and an initial concentration of dopant imparting an initial conductivity type;

at least one epitaxial layer on said first surface of silicon carbide substrate;

a zone of increased carrier concentration in said silicon carbide substrate and extending from said second surface of said silicon carbide substrate toward said first surface, said zone of dopant material being characterized by a concentration of dopant that progressively decreases from said second surface toward said first surface; and

a nickel ohmic contact on said second surface of said silicon carbide substrate.

23. A semiconductor device according to claim 22 wherein the implanted dopant material is selected from the group consisting of nitrogen, aluminum, arsenic, phosphorous, boron and gallium.

24. A semiconductor device according to claim 22 wherein the initial carrier concentration in the silicon carbide is between about $1x10^{15}$ to about $1x10^{19}$ cm^{-3}.

25. A semiconductor device according to claim 24 wherein the carrier concentration in the zone of increased carrier concentration is between about $1x10^{18}$ and about $1x10^{20}$ cm^{-3} and is greater than the initial carrier concentration in the silicon carbide.

26. A semiconductor device according to claim 22 wherein said epitaxial layers are selected from the group consisting of gallium nitride; aluminum gallium nitride; indium gallium nitride; and oxides of silicon, gallium, aluminum and indium.

27. A semiconductor device according to claim 22 wherein the semiconductor device is a vertical device.